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DRYLAND SALTING AND GROUNDWATER DISCHARGE IN THE VICTORIAN UPLANDS

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Abstract: Secondary dryland salinity in Victoria is the result of increased groundwater recharge and discharge post European settlement. The change in ecology produced by the development of agricultural practices has altered the nature of hydrologic balance of groundwater systems. The ability to store water in the regolith has been depleted and groundwater has risen in the landscape. Additional recharge post clearing is now offset by the development of new groundwater discharge sites and increased baseflow of streams.

Increased groundwater recharge and discharge has occurred since clearing of native vegetation and its subsequent replacement with shallow rooted pastures and crops. The decrease in evapotranspiration has allowed profiles to saturate and drain more frequently causing greater accessions to groundwater. Estimates of current mean annual groundwater recharge generally range from 10-50 mm/yr.

The rise and migration of groundwater through the landscape is leaching ions once stored throughout the regolith toward discharge sites where they appear in stream baseflow, or concentrate in the soil producing affected land. Recharge and discharge of groundwater systems may be confined to particular catchments or sub-catchments or may be independent of topography. The nature of the groundwater system depends on geological and geochemical development of the landscape.

Dryland salting is particularly severe and extensive where the pallid zone clays of deeply weathered landscapes are semi-confining to groundwater discharge. Catchments within these landscapes appear to possess a groundwater balance independent of adjacent catchments. Conversely landscapes which do not have a deeply weathered regolith appear to possess groundwater systems of a more regional nature, i.e. independent of surface relief. In either situation it is possible to have landscape components which behave as "preferred" intake zones for groundwater recharge, and the significance of these components needs to be assessed in order to gauge the effectiveness of land use changes designed to ameliorate dryland salinity.

The movement of soluble salts in the landscape depends upon the dynamics of water in the zone of weathering. The addition or removal of water may cause dissolution, dilution, precipitation or leaching, and the dominance of any one of these processes is a function of geological, hydrological, geochemical, vegetative and climatic factors. In response to these factors, hydrological conditions developed which tended to store salts within the unsaturated regolith. This was achieved through the agency of native vegetation which maximised water use.

The development of modern agriculture required the removal of native vegetation and its replacement with species possessing different water use characteristics, a change which subsequently produced changes in the hydrological cycle. Saturation and deep drainage beyond the soil and root zones of the upper regolith occurred more frequently and the level of groundwater rose as available storage was depleted. Eventually groundwater reached the surface in the lower landscape, where it now discharges. The groundwater is generally saline because it contains ions leached from the previously unsaturated regolith. The leaching of salts as groundwater migrates toward discharge sites progressively depletes the salt storage of the regolith. Ions may be exported via groundwater baseflow in streams or may concentrate in the soils at the discharge sites.

The environmental effects of saline discharge are increased stream and soil salinity. Soil salinity in discharge areas commonly exceeds that tolerated by common crops and pastures and affected areas frequently become either completely devoid of vegetation or support only the most salt tolerant species.

THE ORIGIN OF SOLUBLE IONS

Water may introduce ions to the landscape through small concentrations in rainfall or by reaction with the minerals in the regolith, releasing ions to solution during the formation of new mineral species.

Ions introduced in the rainfall are believed to be mainly of oceanic origin, contained in the spray produced by the action of wind and waves, although some ions are believed to originate from dust blown up from cultivated soils or from deserts. Ions are progressively removed as they move inland, a general decrease in ionic concentration in rainfall being observed with increasing distance from the coast (Hutton & Leslie 1958). As these ions return to the oceans via overland and subsurface water flow the process as well as the ions involved have been termed "cyclic".

The successive chemical decomposition of both primary and secondary minerals at or near the earth's surface may produce ions in solution. Weathering results in new minerals which are stable within each of a succession of new environments. For instance, the decomposition of orthoclase to muscovite can be expressed as follows:

$$3KAlSi_3O_8 + 2H_2O + 2H^+$$
$$= KAl_3Si_3O_{10}(OH)_2 + 6H_4SiO_4 + 2K^+$$

Thus silica and potassium ions are released to the regolith solution. It is emphasised that the process is not restricted to the decomposition of fresh primary rock-forming minerals, but continues until equilibrium is established between mineral composition and the hydrological environment (Garrels & Christ 1965).

THE EFFECT OF DEEP WEATHERING

The association of deep weathering and saline areas is well known. Most of the severe salinity problems in Western Australia occur on deeply-weathered igneous and metamorphic terrain (Mulcahy 1978). In Victoria, also there are remnant pockets or belts of deeply weathered bedrock, mostly considered to be residuals of deep Tertiary weathering (Gunn & Richardson 1979). This association of salinity problems with deeply and intensely weathered areas is not the result of continuous release of ions during rock weathering as is sometimes stated. Rather, weathering increases the ability of the regolith to store ions, and rock decomposition and the development of clays and silts increases the ability of deep rooted vegetation to penetrate the regolith allowing evapotranspiration over long periods to produce high ion storage characteristics. Peck (1977) noted high concentrations of ions in the root zone of forests in deeply weathered catchments of Western Australia and considered the phenomena to be the result of ion exclusion by trees during soil water use.

The decomposition of rock forming minerals during weathering could not explain high ion storage because the intensive leaching necessary to form the present minerals (mainly kaolin) indicates that ions produced by such water-primary mineral interactions would have been largely removed by percolating solutions. In addition, the geochemistry of the present waters show that they are in equilibrium with the secondary clay minerals and not the primary rock minerals or their immediate decomposition products. The production of kaolinite and other clays has the effect of reducing permeability and tends to produce confining layers in the system. Groundwater moves through such systems only with difficulty and deeply weathered landscapes all appear to possess steep hydraulic gradients with low hydraulic conductivities in the pallid zone.

Deeply weathered profiles, and associated salinity problems occur extensively along the foothills of the Victorian uplands and on the Dundas Tablelands in the southwest. Drilling in these areas has revealed piezometric surfaces which suggest groundwater systems that converge toward valley floors with very marked groundwater divides coincident with topographic divides. The piezometric surface in the valley floor is commonly above ground surface, and bores tend to be artesian. This groundwater system has developed because of increased recharge following agricultural development and the ability to store groundwater within the system has been exhausted, with recharge on the slopes now approximating discharge on the valley floor. Therefore it is proposed that in the present salt-affected, deeply-weathered catchments annual groundwater discharge is close to being in equilibrium with annual groundwater recharge.

A groundwater and salt balance model has been developed for a deeply weathered catchment at Kamarooka, to the north of Bendigo where the upland front disappears beneath the Riverine Plain. Discharge occurs at the break of slope between the plain and the uplands where the groundwater capillary fringe reaches the surface. This generally occurs where groundwater is present within 1.5 metres of the surface. Further, the groundwater catchment is well defined and coincides with the surface catchment. In this case, approximately 1700 ha of recharge area contribute groundwater to 390 ha of discharge area. Calculations based on upward groundwater gradients within the discharge area suggest a mean annual discharge of approximately 75 mm/yr. Recharge to groundwater was calculated assuming an equilibrium between recharge and discharge and mean annual recharge was found to be approximately 17 mm/yr. Thus, a recharge of only 17 mm/yr in a 1700 ha catchment will maintain a 390 ha discharge area.

BEDROCK AQUIFERS OF THE WESTERN UPLANDS

Although dryland salinity problems are generally common and severe in areas that are deeply weathered they are not confined to these. The problem occurs throughout the uplands and again is a feature of groundwater discharge (Jenkin 1979).

The uplands consist mostly of folded sedimentary rock with a well-developed network of joints and other fractures which permit the transmission of water through otherwide almost impermeable rock (Dyson & Jenkin 1981, Jenkin & Dyson 1982), the significance of fractured rock systems has been pointed out by Legrand (1979), and is a phenomenon which has been considerably underrated in the past although it is fundamental to dryland salting in the Victorian Uplands. Although drilling near Eppalock, southeast of Bendigo, has revealed a regional aquifer system with a piezometric surface of very low relief, the relationship between piezometric surface and catchment topography is not yet well defined. Adjacent catchments have piezometric surfaces at similar elevations but these vary with time in response to rainfall and drought. On a regional basis, the low relief of the piezometric surface in relation to topography suggests a high fracture permeability. In both forested and cleared catchments, piezometric surfaces have been revealed at depths ranging from 10 to 40 m below the ground surface, depending on topography. The forested catchment is approximately 2 km southwest of the cleared catchment and some 30-40 m higher, but the piezometric surface is at about the same level for both catchments, that is 209-210 m above sea level.

The rise in this regional groundwater system is responsible for the present salinity phenomena within the Uplands. The regional groundwater now intersects the lower ground surfaces, where it discharges, salinising land and increasing saline baseflow in streams.

RECHARGE TO FRACTURED ROCK AQUIFERS

The accession of water to regional groundwater systems seems to occur universally throughout the Uplands. However, recent work on the hydrological properties of soils in the region suggests that, while recharge occurs throughout the landscape it may be much lower on the valley floors and lower slopes compared with the upper slopes (Dyson & Jenkin 1981). The former carry duplex soils with a sandy loam about 10-15 cm thick overlying approximately 50-70 cm of medium clay. The clays are sodic leading to the upper B horizon being relatively impermeable, with infiltration rates of about 5 mm/day. The upper slopes and rocky ridges typically have thin, skeletal, uniform or gradational soils which exhibit high, although extremely variable saturated infiltration characteristics (300 mm/day and sometimes greater). It follows that these areas would contribute significantly to recharge if their areal extent within the catchment is sufficiently large. For example, water and salt balance studies of streams throughout northern Victoria suggest that mean annual recharge is between 10 mm/year and 40 mm/year (D. Williamson pers. comm.). These figures are calculated for the catchment as a whole unit and it assumes that recharge is evenly distributed. However, if we partition this recharge for the total catchment between the higher infiltration zones of the upper slopes and the remainder of the catchment, and successively increment recharge in the "critical" area, the sensitivity of this land component can be gauged. The results of this simulation are presented in Table 1 assuming an overall catchment recharge of 20 mm.

Table 1 indicates that the upper slope gradational soils and rocky ridge country may be a critical component in affecting the recharge to regional fractured rock aquifers. Up to 30% of a catchment on the northern slopes of the uplands may consist of this component as a study of the Axe Creek catchment near Bendigo has shown (J. S. Duff pers. comm.). Partitioning calculations based on this figure show that 65 mm of recharge within this area implies less than 1 mm of recharge over the remainder of the catchment. Furthermore, if we accept these recharge figures, this area would be expected to supply 83% of the annual groundwater accession within the catchment.

The presence and distribution of groundwater divides coinciding with topographic divides in these areas has yet to be investigated. There is a dearth of information concerning the fractured rock aquifers of the Uplands, and hydrological characteristics including hydraulic gradients, potentiometric surfaces, storage coefficients and hydraulic conductivity are not yet available. Estimates at present are based on very limited data; thus Plier Malone (1982) considers that gross hydraulic conductivity is probably several metres per day and classical techniques for determining these properties are usually not applicable to fractured rock aquifer systems (Legrand 1979). It is clear that a much better understanding of the groundwater regime of the uplands is essential before land use management systems aimed at reducing groundwater recharge can be recommended with confidence.

TABLE 1
SIMULATION OF SIGNIFICANCE TO GROUNDWATER OF A CRITICAL COMPONENT WITHIN A CATCHMENT ASSUMING AN OVERALL CATCHMENT RECHARGE OF 20 MM/YR

Component area (% of catchment)	Assumed recharge (mm) and groundwater contribution (%)		Recharge in remaining catchment (mm) and groundwater contribution (%)	
	mm	%	mm	%
10	50	13	16.6	87
10	100	32	11.1	68
10	180	81	2.2	19
20	30	8	17.5	92
20	60	24	10	76
20	95	80	1.3	20
30	30	9	16	91
30	50	27	7.1	73
30	65	83	0.7	17

EFFECT OF SOIL AND VEGETATION ON GROUNDWATER RECHARGE

Increased groundwater recharge following clearing and agricultural development, and the subsequent development of groundwater discharge, has created a groundwater flow system that is effectively leaching ions, once stored throughout the regolith, toward the discharge sites. Less recharge occurs under forest than under cleared land since the frequency of soil saturation and deep percolation there is much less. For example a paired catchment study of forest and cleared land near Bendigo (Dyson & Jenkin 1980) showed that forest catchments maintain the soil water content at or close to wilting point for most of the year, while cleared catchments with shallow-rooted native pastures may be at field capacity for up to six months at a time. The deep-rooted forests, through evapotranspiration, maintain the ability of the soils to store soil water, consequently, these seldom saturate and drain. The cleared land with shallow-rooted pastures, however, is unable to store water through the late Autumn-early Spring period and saturation, deep percolation and groundwater recharge occur following rainfall.

The role of vegetation is also reflected in the groundwater hydrographs of the forested and cleared catchments (Fig. 1). During 1981, piezometric heads in all cleared catchments monitored rose by 0.5-0.75 m, while heads under forested catchments remained unchanged. However, the effect of forest cover does not extend into the adjacent cleared land as piezometers located at forest margins also exhibited increased heads.

The variation in piezometric surface throughout 1981-82 is an indication of the dynamic nature of this deep regional groundwater. The 1981 year was one of the highest rainfall years on record and 1982 one of the

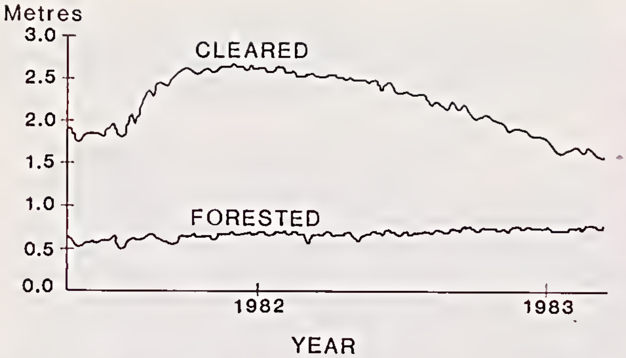

Fig. 1—Fluctuations of potentiometric levels (above 210 m datum) with time—forested and cleared catchments.

driest. Groundwaters of the cleared catchment have responded accordingly (Fig. 1). Piezometric heads rose during the very wet winter and continued to rise despite lack of rainfall until early summer when they began to decline. Heads have continued to steadily decline to the present date (March, 1983), principally because of lack of rainfall.

SUMMARY AND CONCLUSIONS

Secondary dryland salinity throughout Victoria is mostly the result of saline groundwater discharge. Changes in ecology have occurred since European settlement with the development of current agricultural practices. This has altered the magnitude of components of the hydrological cycle. The ability to store water in groundwater systems has been depleted and groundwater now discharges where previously, under natural conditions, it did not do so.

In many areas, discharge is inhibited by overlying clayey alluvium or by the heavy clay pallid zone of lateritic remnants which occur as isolated pockets throughout the Uplands, along the upland front, and extensions in the Dundas Tablelands. In these circumstances, groundwater becomes semi-confined and deep wells and piezometers are often artesian. Large areas of salt-affected land are common in such landscapes and are necesary to maintain the present approximate hydrological balance between recharge and discharge, i.e. the area of discharge sites (where groundwater moves upward through slowly permeable semi-confining layers) must be large enough to dispose of the volume of water from recharge sites.

However, where groundwater is unconfined, saline discharge occurs in the lower areas as the water table reaches the surface. This occurs in many instances throughout the Uplands where stream and river erosion has exposed the bedrock aquifer. Recharge to these aquifers is also related to low water use by vegetation, although the hydrological properties of the soils suggest that some land components may be more important than others. In particular, the shallow gradational soils and rocky ridge land component may contribute far more to recharge than the valley slopes and floors which generally carry well-developed duplex soils with medium to heavy clay subsoils.

Increased groundwater recharge following European settlement is the result of decreased water usage in the new ecology. Water passes beyond the shallow root zone of the introduced species and the soil saturates and drains to the underlying groundwater more frequently. Groundwater migrates from recharge sites to discharge sites and the activation of these flow systems is progressively leaching ions once stored in the unsaturated regolith. These ions now appear in the baseflow component of streams or concentrate by evaporation in surface soils of discharge zones, producing salt affected land.

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